Investigating the Effect of Surface Texture on Friction and Wear in Sliding Contacts

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Abstract

Numerous industrial applications have shown that altering the surface geometry enhances the tribological performance of lubricated sliding contacts.The purpose of the current study is to look at how surface roughness affects wear and friction in sliding contacts. The performance and durability of many engineering systems, including mechanical parts, bearings, and automotive applications, are significantly influenced by friction and wear. Understanding how surface texture affects these tribological processes can help us improve efficiency and lower energy losses in these systems. In this paper discussed the surface roughness has a big impact on how friction and wear behave in sliding contacts. When compared to smoother surfaces, it was found that some texture patterns, such as micro-grooves and dimples, have lower friction coefficients and wear rates. This is due to the smaller contact area, enhanced lubrication, and increased oil retention capacity offered by the surface roughness. The directionality of the textures also significantly affected how well they performed tribologically, with some orientations performing better than others.The study found that the ideal surface roughness for reducing friction and wear depends on the particular operating circumstances. When choosing a suitable texture pattern, factors including load, sliding speed, and lubricant type must be taken into account.

Keywords: Numerical modelling, lubricated sliding contact, surface texturing, film thickness, texturing patterns

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1. Introduction

Due to resource depletion and environmental consequences, efficient energy use is a top priority that is constantly growing in importance across all industrial sectors and society as a whole [1],[2]. Currently, it is estimated that just a third of the world's energy resources are used to reduce friction in mechanical systems [3].Increasingly, there is a burgeoning need to enhance the tribological performance, specifically the frictional behavior, of lubricated sliding contacts in numerous applications. The conventional approach to reducing friction involves achieving smoother surfaces. Nevertheless, the pursuit of super-smooth surfaces can be cost-prohibitive and may potentially lead to failures [4].As a creative engineering approach, surface texturing has the potential to improve the tribological performance of mechanical components [5]. Despite notable improvements in processing methods, characterisation strategies, and computational algorithms, there is still a critical knowledge gap regarding how surface textures work. Although the advantages of surface texturing have been seen, there is still a lack of a complete knowledge of the underlying mechanisms and principles. Therefore, more research is required to understand the complex relationships between surface textures and tribological behaviour, allowing for the creation of optimised texturing techniques for better performance.

Many studies in the field have looked into how surface texturing affects the transitions between various lubrication regimes. Researchers have worked hard to characterise the Stribeck-like curves for both textured and untextured materials in order to achieve this. In order to understand the mechanisms governing lubrication transitions and the part surface texturing plays in these events, these studies analyse and evaluate the lubrication performance of various surface textures under a range of operating situations.

Experimental findings that have been published [6] have shown that surface texturing is essential for quickening the change from boundary to mixed lubrication. Surface textures considerably speed up this transition as compared to surfaces without them. Furthermore, these investigations have demonstrated a significant decrease in the coefficient of friction when mixed lubrication conditions are applied to textured surfaces. In conclusion, surface texturing has significant advantages by accelerating the transition from one lubrication regime to another and lowering frictional resistance in sliding contacts.The laser-textured samples in a similar work by Borghi et al. [7] demonstrated an impressive 75% reduction in friction. The transition from mixed to full film lubrication was shifted to lower sliding velocities, the authors further established, as a result of laser texturing. These results demonstrate the effectiveness of laser texturing in lowering friction and enabling full film lubrication at lower operating speeds.Segu et al. [8] presented a novel method using multi-scale textures that combine ellipses and dimples to speed up transitions between lubrication regimes and lower friction in conformal situations. Similar results were seen in non-conformal settings with a multiscale texture made up of squares and triangles [9].By include scattered hemispherical micro-dimples on one of the mating seal surfaces, Etsion et al.'s [10] theoretical model for mechanical seals revealed appreciable increases in seal performance. The spherical dimple shape can then be optimised, together with the optimal depth to diameter ratio, to further increase the tribological efficacy of oil-lubricated laser-textured seal rings as shown by an experimental model [11]. These results show that the performance and effectiveness of mechanical seals in oil-lubricated contacts can be greatly improved by surface texturing, particularly with hemispherical micro-dimples.

Fillon's team performed theoretical analyses to assess the tribological capabilities of hydrodynamic thrust bearings with and without texturing under low and high normal loads and experimental studies [12]. Their research showed that surface texturing reduced friction by up to 30% at low loads. However, there was no discernible benefit from surface texturing under heavy pressures. Reddyhoff's group, on the other hand, reported contradictory experimental results [13], indicating the need for additional study to resolve these contradictions and gain a thorough understanding of the impact of surface texturing on tribological performance in hydrodynamic thrust bearings under various load conditions.The authors tested textured convergent-divergent bearings using a reciprocating test setup to evaluate friction and film thickness. They used precise optical interferometry to quantify the film thickness at the ultra-thin level. Under complete film lubrication circumstances, the results showed that the surface texture increased friction, which was ascribed to the surface roughness's increased shear rate.

With the use of femtosecond lasers, improvements in the field of laser texturing have been developed, allowing for improved versatility in processing a variety of materials, from metals to ceramics and glasses. However, creating complex surface textures with various sizes and forms is a basic problem for Laser Surface Texturing (LST). Direct Laser Interference Patterning (DLIP), which uses multiple laser beam interference to produce complicated surface textures in a single step, has been created to get around this constraint.When evaluating the cost-effectiveness of surface texturing for a particular application, it is vital to take other techniques into account in addition to DLIP, which offers a potential method for creating complex textures. Consideration should be given to a number of potential methodologies, taking into account things like the required texture complexity, implementation costs, and compatibility with the materials in question. Manufacturers and researchers can choose the best surface texturing approach for their particular application by carefully weighing a variety of techniques.

This study's goal is to investigate how friction on textured surfaces with oil lubrication is affected by lower dimple sizes. The samples were created using Laser Surface Texturing (LST), and after they had been tested utilising a specially designed reciprocating test rig, they were assessed. The primary goal of the study is to better understand how friction behaviour on textured surfaces with oil lubrication is affected by decreasing dimple sizes.The results of the study show that smaller dimples can successfully lessen friction. The friction coefficient then rises as a result of the regular wear process gradually removing the surface textures. This finding points to a novel method of surface texturing that makes use of ceramics and other materials with low wear rates. By using such materials, it would be able to prolong the benefits of surface texturing while reducing the rise in friction coefficient brought on by wear.

I. Materials and Techniques

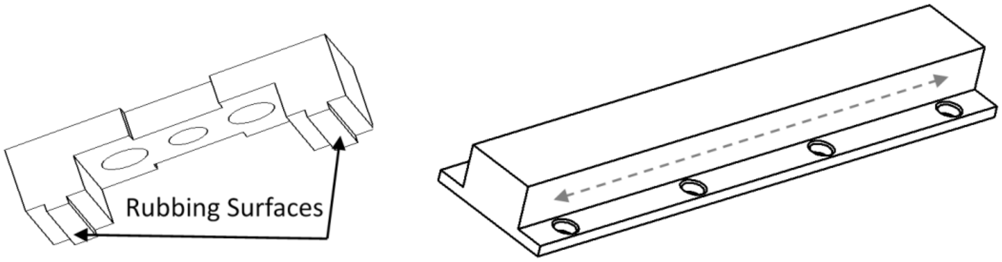
The study of this discussed, Hamilton et al. [14] noted the occurrence of pressure amplification happening in the converging film regions, followed by a drop in pressure within the diverging film sections in their examination of face seals. This pressure change is also seen when a cavity is present that was created using a method like laser surface texturing.Between hydrodynamic lubrication (HL) and boundary lubrication (BL), the mixed lubrication (ML) regime acts as a transitional phase. It can be characterised as a hybrid regime that combines the traits of the two. Between the values seen in the BL and HL regimes, the coefficient of friction in the ML regime exhibits a range of values. In order to fully grasp the tribological properties of the ML regime, researchers mostly use experimental approaches to explore and analyse its behaviour.Gelinck and Schipper [15] built on the preexisting model by enlarging it to include line contacts, allowing for the estimation of the Stribeck curve. A mixed lubrication model that incorporates surface shear deformation and inter-asperity cavitation was put forth by Shi and Salant [16] with soft materials in mind. Their research shed light on the complex behaviour of lubricated surfaces in soft materials by demonstrating the presence of local cavitation within the mixed lubrication regime.

The Jakobsson-Floberg-Olsson model is frequently used as a cavitation hypothesis in moderately loaded lubricated systems [17, 18]. It's crucial to remember that when the surface tension effect is considerable, the model's dependability declines [18]. To overcome this issue, a numerical model was created in the study of Faraon et al. [19]. The model takes into account the existence of local cavitation inside the contact zone and is based on a deterministic mixed lubrication technique. This model offers a different method for analysing lubricated systems under various circumstances and offers insightful information on the behaviour of lubricants in the presence of local cavitation. The results of a prior study [20] that assessed film thickness and used a deterministic asperity contact model to compute friction are used in the current investigation to estimate friction. The created model provides improved insights into the effect of surface texture features on friction within the mixed lubrication regime by incorporating these results. This all-encompassing strategy strives to enhance knowledge of how surface texture affects frictional behaviour under mixed lubrication circumstances.

II. Experimental

a. Description of Samples:

The friction pair employed in this study was made up of a flat cast iron slider and a sample made of SAE 1035 steel with a chrome finish. As seen in Figure 1a, the sample had a particular geometry with two holes for thermocouple insertion and a third hole in the middle for oil lubricant delivery. All samples' surfaces were polished with lapping procedures to a roughness of roughly Ra = 340 nm on average. Specifically, the Wyko NT1100 model of a 3D optical profilometer was used to quantify the surface roughness.

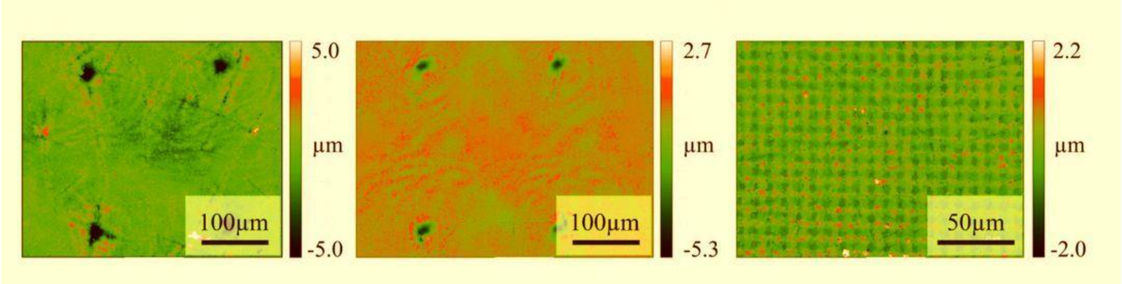


(a) (b)

Figure 1: (a)Specimen geometry(b)the shape of the slider

b) Laser Texturization

In the experiment, four samples with various laser textures were evaluated. Optimised parameters were used to create the dimples in the reference sample (sample d). An ultrashort-pulsed laser was used to make varied dimples in two materials (a and b). A grid-like pattern was created on a different sample (sample c) using direct laser interference patterning (DLIP).



(a) (b) (c)

Figure 2: The cross-sectional profiles of samples (a) and (b) with ultrashort laser textures and sample (c) with a grid-like pattern created by direct laser interference patterning are shown in the 3D optical profilometer photographs.

Three textured samples (a, b, and c) are shown in cross-sectional profile plots and 3D optical profilometer pictures in Figure 2. The same SAE 1035 steel coated with chrome was used to build these examples. A linear p-polarized ultrashort-pulsed Ti:Sapphire laser from Spectra-Physics, Spitfire Pro, Darmstadt, Germany was used to texture the steel surfaces and produce laser dimples (samples a and b). The laser produced light with an approximate wavelength of 800 nm, a pulse width of 120 fs, and a repetition rate of 1 kHz.Three important factors were taken into account when creating the dimples: dimple diameter, depth, and spacing between the dimples. To achieve exact positioning, the samples were mounted on an xy motorised table with micron accuracy.Each dimple received 20 laser pulses, which were applied successively. The laser power of the output beam was calculated while the number of pulses was manually adjusted.A fourth sample, known as the "Reference" sample in this investigation, was further created using the same steel material and textured in accordance with the ideal feature parameters specified in Reference [21]. These texturing elements were found in the reference to produce the best frictional performance, leading to less friction. The different samples are listed in Table 1, together with their distinctive characteristics and sizes.

Table 1: The details on the sizes and shapes of the various sample features.

Sample	**Texture and Form**	**Dimple Size (µm)**	**Dimple Depth (µm)**	**Distance between Dimples (µm)**
a	The Dimples	25	4-5	200
b	The Dimples	30	4-5	200
c	Grid-like Structure	-	1.9	9 (periodicity)
d	The Dimples	100	10	250

c) Test Rig Information

The frictional performance was evaluated using the custom test rig created by the Technion Tribology Laboratory. This test system, which is fully described in Reference [21], enables the measurement of friction force, wear, and surface temperature. It is designed to mimic the reciprocating motion of automotive components, making it appropriate for studying the impact of surface texturing on friction and wear under full and starved lubrication conditions.

The test apparatus consists of several components, including an electric motor (1) that rotates at various angles, a crank mechanism (2) that reciprocates the linear stage with its slider counterpart (3), two guides (4) connected to a common base, and more. Elastomer dampening pads are used to insulate the base from the laboratory floor to decrease the effects of vibration. A deadweight (5) applies the usual load. Friction force is measured using a customised instrument composed of an elastic beam (6) and a proximity probe (7). The proximity probe detects variations in clearing time corresponding to changes in friction force as the elastic beam deflects in reaction to the friction force. By precisely calibrating the proximity probe's output signal using precise weights, the friction force value is determined. By integrating the absolute value of the time-dependent friction force over a single cycle loop, the average friction is calculated. The friction force measurement has an accuracy of 5% and a resolution of about 0.1 N.

An optical gauge is used to record measurements of reciprocating speed, such as average speed and crankshaft rotation frequency. Using a specially created holder mechanism, adequate contact conformance between the samples is ensured. It permits the sample to self-align with regard to the corresponding plane slider, applies the standard load to the holder, makes it easier to feed lubricant into the contact zone through a central oil conduit, and allows for the embedding of thermocouples in the holder for temperature measurements.The test rig offers a thorough way to assess friction and wear properties, enabling controlled testing and precise data collection.

d) Test Process

The sample is brought into contact with the slider during the friction test while the deadweight applies a specified contact pressure. The electric motor then starts the slider moving back and forth at the indicated "U" velocity. Electrical heaters are used to heat the sample to a temperature between 60 and 70 °C in order to maintain constant test conditions. Thermocouples are used to measure temperature, and they are positioned 4 mm below the friction surface.A completely formulated 15W40 mineral oil is used for lubrication. The oil possesses distinct characteristics, such as a density of 0.8414 g/cm3 at 80 °C, a kinematic viscosity of 23 mm/s at 80 °C, a mass content of zinc of 0.126%, a mass content of phosphorus of 0.155%, and a mass content of sulphated ash of 0.99%.Three drops of oil are delivered to the contact area every minute using a nozzle, maintaining a constant lubrication condition during the test.

The maximum speed that could be achieved on the experimental test rig without causing dynamic disturbances was 500 rpm, so that's what we set the motor's rotational speed to. This rate equated to an average sliding speed between the slider and the specimen of 1.75 m/s. A stroke length of 0.1 m served as the basis for the calculations for the exam.

It is significant to remember that after the friction test, the specimens' surface topography was assessed. This made it possible to evaluate any changes in surface properties brought on by the test.

Table 2: The summary of the experiment's circumstances.

Parameters	**Data Range**
Speed of Motor Rotation	600
Contact Force	0.18
Surface Temp (in centigrate)	65-75
Lubricant Rate	3 drop per min

III. Result and Its Discussion

As previously mentioned, four samples were evaluated on the reciprocating test rig under the operational circumstances listed in Table 2. For sample (a), depicts the friction force variation across a number of crank revolutions. The slider's reciprocating action, which causes the elastic beam to deflect, is represented by the alternating positive and negative numbers. The measured values in Figure 3 have an accuracy of 3% and a resolution of about 0.06 N.

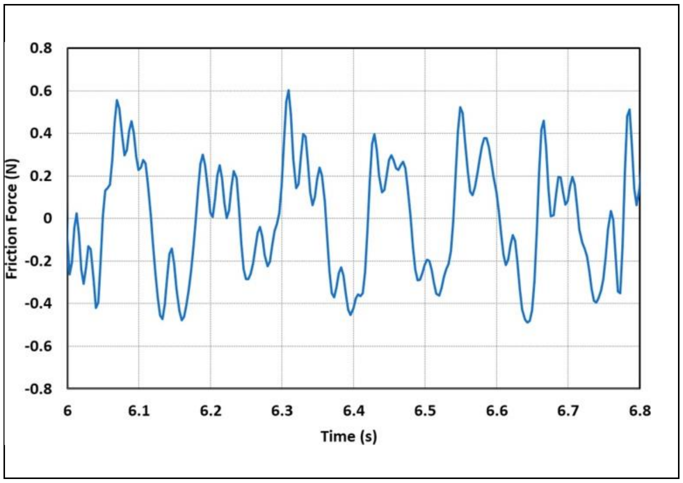


Figure 3: Function of time during subsequent revolutions, friction force

The average friction coefficient is calculated by integrating the absolute value of the time-dependent friction coefficient across a single cycle and dividing the observed friction force by the applied normal load. Figure 4 displays the average absolute value of the friction coefficient as it evolved throughout the test.

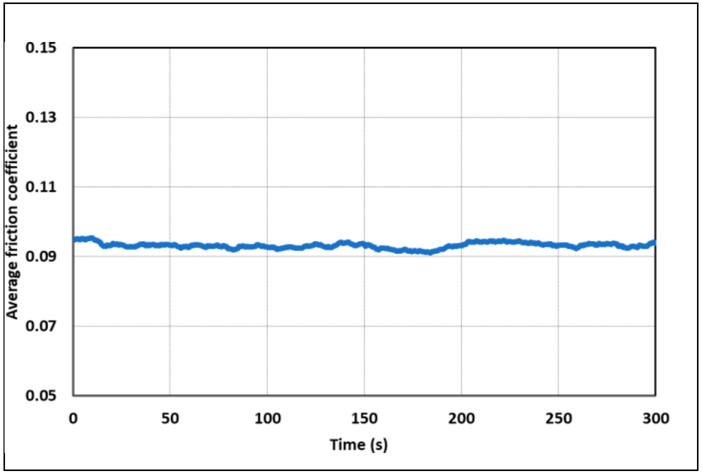


Figure 4: Friction Coefficient with Average absolute value

In Figure 4, the average friction coefficient reaches a steady state and stays around this level for the duration of the test. To assess the overall impact of the various surface textures on friction performance during reciprocating motion, the absolute values of the friction coefficients were averaged for each sample. Figure 5 shows the computed and displayed error bars. The graph clearly shows that samples a and b have lower friction coefficients than the d-reference sample does. On the other hand, sample c exhibits a greater friction coefficient due to its surface pattern resembling a grid.There is a significant relationship between the number of dimples, linked roughness, and edge stresses, as well as boundary lubrication. It strikes a balance between dimple density, size, and shape as a result. The ability to hold lubricant in the pockets is higher in smaller dimples with an average area density between 5 and 8 percent, which results in decreased friction.

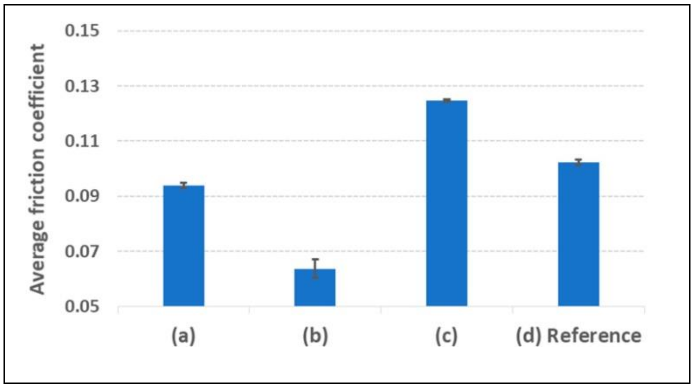


Figure 5: The typical friction coefficient for the various samples evaluated.

IV. Conclusion

This experiment looked at how the surface texture of textured surfaces affected friction performance when they were in contact with each other while being lubricated reciprocally. Using a direct laser interference pattern and an ultrashort pulsed laser, four steel samples with chromium coatings were textured. Using a specially made reciprocal test rig, friction tests were performed with contact pressures of 0.18 MPa, motor speeds of 600 RPM, contact temperatures of 65–75 C, and oil feeding rates of 3 drops per minute with 15W40 oil. For each cycle, the absolute average friction coefficient was calculated. These findings were contrasted with a reference sample that had dimples that were 100 m in diameter and 10 m in depth.

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